

We claim:

1. A method of processing a received signal y
to produce a channel estimate comprising:
 - 5 (a) decoding the received signal y to form data
 s ;
 - (b) forming a convolution matrix \hat{S} from the
data s ;
 - (c) forming a matrix F from the data s , wherein
10 the matrix F results from forming the matrix \hat{S} as a
convolution matrix; and,
 - (d) performing a conjugate gradient algorithm
to determine the channel estimate, wherein the conjugate
gradient algorithm is based on the received signal y , the
15 matrix \hat{S} , and the matrix F .

2. The method of claim 1 wherein the
performing of a conjugate gradient algorithm comprises
determining a quantity q_k according to the following
20 equation:

$$q_k = \hat{S}^T \hat{S} d_k,$$

wherein d_k is dependent upon the received signal y , the matrix \hat{S} , and the matrix F , and wherein q_k is determined by forming a first FFT of the matrix \hat{S} , by forming a second FFT of the matrix \hat{S}^T , by forming a third FFT of d_k , by multiplying the first, second, and third FFTs to produce a multiplication result, and by forming an inverse FFT of the multiplication result.

3. The method of claim 1 wherein the forming
10 of a matrix \hat{S} from the data s comprises:

forming a matrix S from the data s ; and,

forming the matrix \hat{S} from the matrix S by
setting certain values of the matrix S to zero;

and wherein the forming of a matrix F from the
15 data s comprises:

forming the matrix F from the matrix S by
setting to zero the values of the matrix S not set to
zero during the forming of the matrix \hat{S} .

20 4. The method of claim 3 wherein the
performing of a conjugate gradient algorithm comprises
determining a quantity q_k according to the following
equation:

$$q_k = \hat{S}^T \hat{S} d_k,$$

wherein d_k is dependent upon the received signal y , the matrix \hat{S} , and the matrix F , and wherein q_k is determined
5 by forming a first FFT of the matrix \hat{S} , by forming a second FFT of the matrix \hat{S}^T , by forming a third FFT of the d_k , by multiplying the first, second, and third FFTs to produce a multiplication result, and by forming an inverse FFT of the multiplication result.

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5. The equalizer of claim 1 wherein the performing of a conjugate gradient algorithm to determine the channel estimate h comprises performing the following algorithm:

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$$(1) \quad \hat{y} = y - Fh_1,$$

$$r_1 = \hat{S}^T \hat{y} - \hat{S}^T \hat{S} h_1$$

(2) For $k = 1$ to n , iteratively calculate

$$(a) \quad d_k = r_k + \beta_k d_{k-1}$$

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$$(b) \quad h_{k+1} = h_k + \alpha_k d_k$$

$$(c) \quad r_{k+1} = r_k - \alpha_k q_{k-1}$$

where h_1 is an initial value of the channel estimate,

where $\beta_1 = 0$, $\beta_{k \geq 2} = \frac{r_k^T \bullet r_k}{r_{k-1}^T \bullet r_{k-1}}$, where $\alpha_k = \frac{r_k^T \bullet r_k}{d_k \bullet q_k}$, where

$q_k = S^T S d_k$.

5 6. The method of claim 5 wherein the
performing of a conjugate gradient algorithm comprises
determining the quantity q_k by forming a first FFT of the
matrix \hat{S} , by forming a second FFT of the matrix \hat{S}^T , by
forming a third FFT of d_k , by multiplying the first,
10 second, and third FFTs to produce a multiplication
result, and by forming an inverse FFT of the
multiplication result.

7. The method of claim 5 wherein the forming
15 of a matrix \hat{S} from the data s comprises:

forming a matrix S from the data s ; and,

forming the matrix \hat{S} from the matrix S by

setting certain values of the matrix S to zero;

and wherein the forming of a matrix F from the
20 data s comprises:

forming the matrix F from the matrix S by

setting to zero the values of the matrix S not set to

zero during forming of the matrix \hat{S} .

8. The method of claim 7 wherein the performing of a conjugate gradient algorithm comprises determining the quantity q_k by forming a first FFT of the matrix \hat{S} , by forming a second FFT of the matrix \hat{S}^T , by forming a third FFT of the d_k , by multiplying the first, second, and third FFTs to produce a multiplication result, and by forming an inverse FFT of the multiplication result.

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9. A method of processing a received signal y comprising:

- (a) decoding the received signal y to form data s ;
- 15 (b) forming a convolution matrix \hat{S} from the data s ;
- (c) forming a matrix F from the data s , wherein the matrix F results from forming the matrix \hat{S} as a convolution matrix; and,
- 20 (d) performing a conjugate gradient algorithm based on the received signal y , the matrix \hat{S} , and the matrix F .

10. The method of claim 9 wherein the performing of a conjugate gradient algorithm comprises determining a quantity q_k according to the following equation:

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$$q_k = \hat{S}^T \hat{S} d_k,$$

wherein d_k is dependent upon the received signal y , the matrix \hat{S} , and the matrix F , and wherein q_k is determined
10 by forming a first FFT of the matrix \hat{S} , by forming a second FFT of the matrix \hat{S}^T , by forming a third FFT of the d_k , by multiplying the first, second, and third FFTs to produce a multiplication result, and by forming an inverse FFT of the multiplication result.

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11. The method of claim 9 wherein the forming of a matrix \hat{S} from the data s comprises:

forming a matrix S from the data s ; and,

forming the matrix \hat{S} from the matrix S by

20 setting certain values of the matrix S to zero;

and wherein the forming of a matrix F from the data s comprises:

forming the matrix F from the matrix S by
setting to zero the values of the matrix S not set to
zero during forming of the matrix \hat{S} .

5 12. The method of claim 11 wherein the
performing of a conjugate gradient algorithm comprises
determining a quantity q_k according to the following
equation:

10
$$q_k = \hat{S}^T \hat{S} d_k,$$

wherein d_k is dependent upon the received signal y, the
matrix \hat{S} , and the matrix F, and wherein q_k is determined
by forming a first FFT of the matrix \hat{S} , by forming a
15 second FFT of the matrix \hat{S}^T , by forming a third FFT of
the d_k , by multiplying the first, second, and third FFTs
to produce a multiplication result, and by forming an
inverse FFT of the multiplication result.

13. A method of processing a received signal
y comprising:

(a) decoding the received signal y to form data
s;

5 (b) forming a convolution matrix \hat{S} from the
data s;

(c) forming a matrix F from the data s, wherein
the matrix F results from forming the matrix \hat{S} as a
convolution matrix; and,

10 (d) performing a conjugate gradient algorithm
based on the received signal y, the matrix \hat{S} , and the
matrix F, wherein the conjugate gradient algorithm
includes forming FFTs based on the received signal y, the
matrix \hat{S} , and the matrix F, multiplying the FFTs to form
15 a multiplication product, and forming an inverse FFT of
the multiplication product.

14. The method of claim 13 wherein the
performing of a conjugate gradient algorithm comprises
20 determining a quantity q_k according to the following
equation:

$$q_k = \hat{S}^T \hat{S} d_k,$$

wherein d_k is dependent upon the received signal y , the
matrix \hat{S} , and the matrix F , and wherein q_k is determined
by forming a first FFT of the matrix \hat{S} , by forming a
second FFT of the matrix \hat{S}^T , by forming a third FFT of
5 the d_k , by multiplying the first, second, and third FFTs
to produce a multiplication result, and by forming an
inverse FFT of the multiplication result.

15. The method of claim 13 wherein the forming
10 of a matrix \hat{S} from the data s comprises:

forming a matrix S from the data s ; and,

forming the matrix \hat{S} from the matrix S by
setting certain values of the matrix S to zero;

and wherein the forming of a matrix F from the
15 data s comprises:

forming the matrix F from the matrix S by
setting to zero the values of the matrix S not set to
zero during forming of the matrix \hat{S} .

20 16. The method of claim 15 wherein the
performing of a conjugate gradient algorithm comprises
determining a quantity q_k according to the following
equation:

$$q_k = \hat{S}^T \hat{S} d_k,$$

wherein d_k is dependent upon the received signal y , the matrix \hat{S} , and the matrix F , and wherein q_k is determined
5 by forming a first FFT of the matrix \hat{S} , by forming a second FFT of the matrix \hat{S}^T , by forming a third FFT of the d_k , by multiplying the first, second, and third FFTs to produce a multiplication result, and by forming an inverse FFT of the multiplication result.

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17. A method of processing a received signal y to produce a channel estimate comprising:

(a) decoding the received signal y to form data s ;

15 (b) forming a convolution matrix \hat{S} from the data s ;

(c) forming a matrix F from the data s , wherein the matrix F results from forming the matrix \hat{S} as a convolution matrix; and,

20 (d) performing a conjugate gradient algorithm to determine the channel estimate, wherein the conjugate gradient algorithm is based on the received signal y , the matrix \hat{S} , and the matrix F , and wherein the conjugate gradient algorithm includes forming FFTs based on the

received signal y , the matrix \hat{S} , and the matrix F ,
multiplying the FFTs to form a multiplication product,
and forming an inverse FFT of the multiplication product.

5 18. The method of claim 17 wherein the
performing of a conjugate gradient algorithm comprises
determining a quantity q_k according to the following
equation:

10
$$q_k = \hat{S}^T \hat{S} d_k,$$

wherein d_k is dependent upon the received signal y , the
matrix \hat{S} , and the matrix F , and wherein q_k is determined
by forming a first FFT of the matrix \hat{S} , by forming a
15 second FFT of the matrix \hat{S}^T , by forming a third FFT of
 d_k , by multiplying the first, second, and third FFTs to
produce a multiplication result, and by forming an
inverse FFT of the multiplication result.

20 19. The method of claim 17 wherein the forming
of a matrix \hat{S} from the data s comprises:

forming a matrix S from the data s ; and,

forming the matrix \hat{S} from the matrix S by
setting certain values of the matrix S to zero;

and wherein the forming of a matrix F from the data s comprises:

forming the matrix F from the matrix S by setting to zero the values of the matrix S not set to
5 zero during forming of the matrix \hat{S} .

20. The method of claim 19 wherein the performing of a conjugate gradient algorithm comprises determining a quantity q_k according to the following
10 equation:

$$q_k = \hat{S}^T \hat{S} d_k,$$

wherein d_k is dependent upon the received signal y, the
15 matrix \hat{S} , and the matrix F, and wherein q_k is determined by forming a first FFT of the matrix \hat{S} , by forming a second FFT of the matrix \hat{S}^T , by forming a third FFT of the d_k , by multiplying the first, second, and third FFTs to produce a multiplication result, and by forming an
20 inverse FFT of the multiplication result.

21. The equalizer of claim 17 wherein the performing of a conjugate gradient algorithm to determine the channel estimate h comprises performing the following algorithm:

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$$(1) \quad \hat{y} = y - Fh_1,$$

$$r_1 = \hat{S}^T \hat{y} - \hat{S}^T \hat{S} h_1$$

(2) For $k = 1$ to n , iteratively calculate

$$(a) \quad d_k = r_k + \beta_k d_{k-1}$$

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$$(b) \quad h_{k+1} = h_k + \alpha_k d_k$$

$$(c) \quad r_{k+1} = r_k - \alpha_k q_{k-1}$$

where h_1 is an initial value of the channel estimate,

where $\beta_1 = 0$, $\beta_{k \geq 2} = \frac{r_k^T \cdot r_k}{r_{k-1}^T \cdot r_{k-1}}$, where $\alpha_k = \frac{r_k^T \cdot r_k}{d_k \cdot q_k}$, where

15 $q_k = S^T S d_k.$

22. The method of claim 21 wherein the performing of a conjugate gradient algorithm comprises determining the quantity q_k by forming a first FFT of the matrix \hat{S} , by forming a second FFT of the matrix \hat{S}^T , by forming a third FFT of d_k , by multiplying the first, second, and third FFTs to produce a multiplication

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result, and by forming an inverse FFT of the multiplication result.

23. The method of claim 21 wherein the
5 forming of a matrix \hat{S} from the data s comprises:
forming a matrix S from the data s ; and,
forming the matrix \hat{S} from the matrix S by
setting certain values of the matrix S to zero;
and wherein the forming of a matrix F from the
10 data s comprises:
forming the matrix F from the matrix S by
setting to zero the values of the matrix S not set to
zero during forming of the matrix \hat{S} .

15 24. The method of claim 23 wherein the
performing of a conjugate gradient algorithm comprises
determining the quantity q_k by forming a first FFT of the
matrix \hat{S} , by forming a second FFT of the matrix \hat{S}^T , by
forming a third FFT of the d_k , by multiplying the first,
20 second, and third FFTs to produce a multiplication
result, and by forming an inverse FFT of the
multiplication result.